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APPLICATION
FOR
UNITED STATES LETTERS PATENT

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TITLE: A NOVEL SEROTONIN-GATED ANION CHANNEL

A NOVEL SEROTONIN-GATED ANION CHANNEL

Cross Reference to Related Applications

5 This application is a continuation-in-part application of U.S.S.N.
09/559,622, filed April 27, 2000, which claims priority from U.S. Provisional
Application Serial Number 60/131,149, filed April 27, 1999.

Statement as to Federally Sponsored Research

10 This research has been funded by NIH Grant R37GM24663. The U.S.
government has certain rights to the invention.

Background of the Invention

 The invention relates to the diagnosis and treatment of conditions
associated with serotonin-mediated cellular responses.

15 The biogenic amine serotonin plays a role in the modulation of neuronal
synaptic events as well as non-neuronal cellular signaling. Serotonin acts by
binding to receptors on a variety of cells. These receptors fall into two broad
functional and structural categories, those acting through G-proteins to mediate
intracellular signaling, and those that form ion channels. It is generally believed
that serotonin may act by binding to either G-protein-coupled seven-pass
20 transmembrane receptors, or serotonin-gated cation channels. There are six major
classes of G-protein-coupled receptors, each with numerous subtypes. Thus far,
there is only one class of serotonin-gated ion channels, the 5-HT₃ receptor.

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G-protein-coupled responses can be either excitatory or inhibitory upon activation by serotonin. Activation of G-protein-coupled receptors by serotonin generally mediates responses which are slower-acting and longer-lasting, while ion channels mediate fast-acting and transitory responses. The 5-HT₃ receptor, comprised of the conducting subunit, 5-HT_{3a} and a regulatory subunit, 5-HT_{3b}, appears to exclusively elicit excitatory responses that are generally fast-acting and transitory.

The 5-HT₃ receptor is selectively permeable to cations only, such as Na⁺ or K⁺, and is very slightly permeable to Ca²⁺. The influx of cations, such as Na⁺ into a cell results in depolarization and excitatory neurotransmission. Efflux of cations, such as K⁺ hyperpolarizes the cell, thereby reducing the likelihood of excitation, and generally leads to inhibitory neurotransmission. Since the resting membrane of a typical cell/neuron is much less permeable to Na⁺ influx than to K⁺ efflux, the opening of a non-selective Na⁺/K⁺ channel, such as the 5-HT₃ receptor leads to a dramatic influx of Na⁺, leading to depolarization and excitation.

15 Serotonin has been implicated in the etiology of many disease states, including depression, panic disorders, obsessive compulsive disorder, cardiac abnormalities, sleep disorders, eating disorders, nausea and vomiting, gastrointestinal cramps, and migraines. G-protein-coupled serotonin receptors have been implicated in the control of mood (5-HT_{1A}), migraine (5-HT_{1B}), pain perception (5-HT_{1D}), smooth muscle contraction (5-HT_{2A}, 5-HT₇), anxiety (5-HT_{2C}), and nausea (5-HT₄). Activation of the 5-HT₃ receptor by serotonin can either stimulate or inhibit cardiac function, induce vasodilation, affect lung and intestinal function, cause pain and sensitization of nociceptive neurons, and induce nausea and vomiting. Not surprisingly, many treatments for these disorders are
25 thought to act through serotonergic pathways.

Several classes of drugs thought to modulate the serotonergic pathway exist. For example, selective serotonin re-uptake inhibitors (SSRIs) are used to treat depression. These antidepressants, including Prozac, Zoloft, and Paxil, are believed to act by potentiating serotonin levels at the synapse. Drugs, such as

5 Imitrex, used to treat migraine headaches, act as selective serotonin receptor agonists. Other groups of drugs used to affect mood include monoamine oxidase inhibitors, and selective serotonin receptor antagonists.

While these drugs are administered to humans to treat the above-described disease states, the patients often unpredictably experience a number of

10 side-effects including insomnia, anxiety, chest pain, hypertension, nausea, anorexia, sweating, chills, vomiting, diarrhea, constipation, decreased libido, and abnormal ejaculation. It has been hypothesized that the side-effects result from multiple receptor activation or inactivation when a serotonin agonist or antagonist is given as a treatment. Some of these improperly activated or inactivated

15 receptors may lead to fast- or slow-acting excitatory responses, or slow-acting inhibitory responses, when really only one specific type of response is desired.

A better understanding of serotonin-associated cellular communication could greatly facilitate the discovery of drugs and therapeutic methodologies to treat a broad range of conditions with fewer of the serious and variable side-effects

20 prevalent with currently available drugs that interface with the serotonin pathway. Exactly how the currently available drugs that interface with the serotonin pathway work is not well understood. Agonists, antagonists, and especially serotonin re-uptake inhibitors could affect numerous serotonin receptor subtypes, and the final outcome may be a combined readout of all these varied, and sometimes

25 antagonistic, pathways. It has been hypothesized that the various undesirable side-

effects of a given drug's action are the result of unwanted activation of the serotonin pathways that are not specific to the condition being treated. Therefore, compounds with a greater specificity for a specific serotonin receptor, for a limited subset of serotonin receptors, or for a specific subtype of a particular class of serotonin receptors would be invaluable to the field of therapeutics for serotonin-mediated disease states.

Summary of the Invention

We have discovered a serotonin-gated ion channel, MOD-1, that is exclusively permeable to chloride ions, and is not permeable to sodium, potassium, or calcium ions. Activation of this anion channel is most likely to result in an inhibitory response. In some circumstances that are dependent on the reversal potential for chloride (which is a function of the concentration of chloride inside and outside the cell) activation of anion channels could result in an excitatory response. Therefore, it is conceivable that activation of a serotonin-gated anion channel could also result in excitatory neurotransmission.

With the discovery of MOD-1 and the serotonin-gated anion channel that it forms, comes the realization that serotonin may mediate fast-acting, and transitory, inhibitory responses in addition to excitatory responses. It is possible that the activation/inactivation of a MOD-1-like serotonin-gated anion channel, in humans, is associated with some of the effects and/or side-effects of existing serotonin-based drugs. It is also conceivable that many of the serotonin-related diseases are exclusively due to defects in, or associated with, a serotonin-gated anion channel. None of the currently available drugs have been designed to effectively and specifically target this receptor. Therefore, the discoveries of a

serotonin-gated anion channel and the gene that encodes it are invaluable tools for use in discovering diagnostic and therapeutic compounds for the detection and treatment of conditions associated with serotonin-mediated cellular responses.

One way in which a serotonin-gated anion channel can be used as a tool in drug discovery is by screening existing drugs or drug candidates for their effects on serotonin-gated anion channel activity. Such an experiment can be done using MOD-1 or other serotonin-gated anion channels from non-mammals, such as nematodes, or from lower mammals or humans. Understanding how drugs affect, or do not affect, this anion channel will lend better insight into the overall effect of a drug's mechanism of action. Also, a better understanding of how this serotonin-gated anion channel is regulated will contribute to a better understanding of how current therapies work. Furthermore, information gained from this screen will permit the development of drugs with higher specificities for a particular type of serotonin-binding receptor that will mediate only the desired response. Such drugs include those which do not activate a serotonin-gated anion channel, but do activate other serotonin receptors; those that act specifically on a serotonin-gated anion channel, but not on other serotonin receptors; or those that activate a subset of the various serotonin receptors.

Methods of drug discovery are not limited to screening available drugs only, but also to all compounds and their derivatives that were extracted or synthesized during the development of a given drug affecting serotonin-mediated cellular processes. Furthermore, a *de novo* screen of chemicals can be conducted, with no bias regarding possible functional relevance, for effects on this class of serotonin-gated anion channels.

In a first aspect, the invention features a substantially pure polypeptide that is a serotonin-gated anion channel. In one embodiment, the polypeptide is a substantially pure serotonin-gated anion channel that is permeable to chloride ions. In another embodiment, the polypeptide is MOD-1. In a further embodiment, the polypeptide is a subunit that makes up a multi-subunit serotonin-gated anion channel, permeable to chloride ions. Preferably this polypeptide is from *Caenorhabditis elegans* (*C. elegans*). More preferably this polypeptide is mammalian. Most preferably this polypeptide is human.

In still another embodiment of the invention, the serotonin-gated anion channel is activated by a lower concentration of serotonin than that required to activate the 5-HT₃ receptor. For example, the serotonin-gated anion channel may have a higher binding affinity for serotonin than the 5-HT₃ receptor. This higher affinity can be assessed by calculating and comparing the dissociation constants of serotonin binding to the 5-HT₃ receptor and to a serotonin-gated anion channel.

In another aspect, the invention features a substantially pure nucleic acid sequence encoding a serotonin-gated anion channel. In one embodiment, the substantially pure nucleic acid sequence encodes a serotonin-gated anion channel that is permeable to chloride ions. In another embodiment, the nucleic acid sequence is *mod-1*, and encodes the MOD-1 polypeptide. Preferably this nucleic acid sequence is from *C. elegans*. More preferably the nucleic acid sequence is mammalian. Most preferably the nucleic acid sequence is human.

In another aspect, the invention features an antibody that preferably specifically binds to a serotonin-gated anion channel. In one embodiment, the antibody binds to a serotonin-gated anion channel that is permeable to chloride ions. This invention includes polyclonal, as well as monoclonal antibodies to the

serotonin-gated anion channel.

In another aspect, the invention features a *C. elegans* strain having a mutant *mod-1* gene. In one embodiment of the invention, the *C. elegans* strain has a mutant *mod-1* gene that does not function as a chloride channel. In another
5 embodiment, the strain has a mutant *mod-1* gene that acts in a dominant-negative manner. In another embodiment, the strain has a mutant *mod-1* gene that encodes a polypeptide that is constitutively active.

In another aspect, the invention features a method for identifying a compound that modulates the biological activity of a serotonin-gated anion
10 channel. The method includes the steps of: (a) administering a test compound to a serotonin-gated anion channel, and (b) assaying a modulation in the biological activity of a serotonin-gated anion channel. Assaying the modulation of biological activity may be done by measuring the current carried through a channel, or by measuring the amount of serotonin binding to a serotonin-gated anion channel.
15 The assay can also be a bioassay that involves measuring the rate of locomotion in nematodes having a serotonin-gated anion channel. In one embodiment, the serotonin-gated anion channel is from nematodes. In another embodiment, the serotonin-gated anion channel is from a rat, mouse, or human, and is inserted into a *C. elegans* that either has or does not have a wild-type *C. elegans* serotonin-gated
20 anion channel. In another embodiment, the serotonin-gated anion channel is a chimeric molecule between the serotonin-gated anion channels from various species. In further various embodiments of this aspect, the channel is in a cell, for example, a neuron or a non-neuronal cell. The channel may also be in a lipid bi-layer, a mammal, or a nematode. In yet another embodiment, the serotonin-gated
25 anion channel comprises sufficient MOD-1 protein to form a serotonin-gated anion

channel.

In the above aspect of the invention, the test compound is administered in the absence or presence of serotonin, and is administered prior to, simultaneously with, or after administration of serotonin. Administration may also be in the absence or presence of known drugs that interface with the serotonin pathway. The modulation of the biological activity may be either agonistic or antagonistic. The compound may also be a cell lysate, or isolated from a cell lysate, and may be administered prior to, simultaneously with, or after administration of serotonin, or any known effector of serotonin-mediated cellular processes.

In another aspect, the invention features a method for treating a condition in a patient by administering an agonist or antagonist of a serotonin-gated anion channel to the patient. Conditions that are treated include migraine headaches, loss of appetite, gain of appetite, insomnia, inability to wake up, memory loss, inability to learn, nausea and vomiting, gastrointestinal cramps, body temperature deregulation, moods, including depression or mania, abnormal sexual or hallucinogenic behavior, abnormal cardiovascular function, abnormal muscle contraction, and abnormal endocrine regulation.

In another aspect, the invention features a diagnostic probe for measurement of a serotonin-gated anion channel, either wild-type or mutant, for detecting conditions associated with serotonin-mediated cellular responses. Measurement of a serotonin-gated anion channel includes, but is not limited to detection of nucleic acid levels that code for a serotonin-gated anion channel, levels of a polypeptide that can function as a serotonin-gated anion channel, single strand confirmation polymorphism analyses, or the flow of current across a

membrane. In one embodiment, the probe is a nucleic acid sequence that encodes a serotonin-gated anion channel, for example, MOD-1, or a polypeptide that is a serotonin-gated anion channel, or an antibody that binds to a serotonin-gated anion channel. In yet another embodiment, the probe is standard electrophysiology voltage clamping equipment that measure the activity of a serotonin-gated anion channel. In still another embodiment, the diagnostic probe is used for pharmacogenetics, i.e., in the analyses of conditions associated with serotonin-mediated cellular responses within an individual, family, or families.

In another aspect, the invention features a method for characterizing drugs associated with serotonin-mediated cellular responses, by measuring serotonin-gated anion channel activity upon drug exposure. The drugs include those already currently available for the treatment of serotonin-mediated responses, as well as small molecules that are similar in structure to these drugs. This invention also includes the discovery of any compounds which have not yet been identified as therapeutic for serotonin-mediated cellular responses.

In another aspect, the invention features a method for decreasing serotonin-gated anion channel function by decreasing the level of a serotonin-gated anion channel polypeptide with antisense RNA to the serotonin-gated anion channel, and the antisense RNA itself. Preferably the level of the serotonin-gated anion channel is decreased at least 25%, more preferably at least 50%, 70%, or 80%, and most preferably at least 95%, compared to a control (e.g., a serotonin-gated anion channel that is not contacted with an antisense RNA, or that is contacted with a nonsense RNA sequence). In addition, preferably the antisense RNA is antisense *mod-1* RNA. Such nucleic acids of the invention and methods for using them may be identified according to a method involving: (a) providing a

cell sample; (b) introducing by transformation into the cell sample, a test nucleic acid sequence for a serotonin-gated anion channel; (c) expressing the test nucleic acid of a serotonin-gated anion channel within the cell sample; and (d) determining whether the cell sample exhibits altered serotonin-gated anion channel activity, whereby either increased or decreased channel activity identifies a nucleic acid which may be used to alter serotonin-gated anion channel function. Preferably the cell is a non-neuronal cell. Most preferably the cell is a neuronal cell.

In another aspect, the invention features a method for decreasing the function of a serotonin-gated anion channel by administering an antibody that specifically binds to a serotonin-gated anion channel, or binds to a peptide from that channel. This method includes, but is not limited to, using an antibody to MOD-1 as the antibody, and a channel formed by any MOD-1 polypeptide as the channel whose function is inhibited. The methods also includes using a mammalian antibody to decrease the function of a mammalian serotonin-gated anion channel. This method also includes administration of the antibody *in vivo* or *in vitro*.

In another aspect, the invention features a method for modulating serotonin-gated anion channel activity using a nucleic acid vector encoding a serotonin-gated anion channel, and administering enough vector to alter activity of the serotonin-gated anion channels of at least one cell. In one embodiment, the vector is operably linked to a promoter. In other embodiments, the vector encodes a wild-type serotonin-gated anion channel or a mutant serotonin-gated anion channel. The mutant serotonin-gated anion channel may include, but is not limited to, a mutant channel that is a loss-of-function mutant, a dominant negative mutant, or a constitutively active mutant. In a preferred embodiment, the nucleic acid

vector encodes a wild-type or mutant MOD-1 polypeptide. In other embodiments, administration may occur *in vitro* or *in vivo*. In further embodiments, the vector encodes a polypeptide that affects the function of a serotonin-gated anion channel, or that affects molecules that are targeted subsequent to activation of a serotonin-gated anion channel. These molecules include, but are not limited to, protein
5 kinases, protein phosphatases, and proteases.

In another aspect, the invention features a method for testing a patient having a serotonin-mediated condition, for his/her pre-disposition to respond to therapy, or to experience side-effects due to administration of a specific therapy.
10 The method comprises:

- (a) determining the characteristics of a serotonin-gated anion channel from tissues of the patient, where the characteristics are indicative of the abnormal activity of a serotonin-gated anion channel; and
- (b) administering to the patient a suitable therapeutic agent relative to
15 the degree of abnormal activity of the serotonin-gated anion channel in step (a).

In various embodiments, the abnormal activity is due to mutations in a serotonin-gated anion channel protein, altered levels of synthesis of mRNA of a serotonin-gated anion channel, altered serotonin-gated anion channel protein levels
20 in tissues. In another embodiment, the method further comprises characterizing other serotonin-mediated receptors in the patients. Therapeutic agents to be used in accordance with the present invention may be selected from the group consisting of inhibitors or activators of serotonin-mediated pathways, including therapeutics which are currently available, as well as those which are discovered,

as described herein.

In accordance with the present invention, there is provided a method for the identification of a patient possessing a serotonin-mediated condition to be responsive to therapies for the condition, or to experience side-effects due to administration of a specific therapy. This method comprises:

(a) determining the characteristics of a serotonin-gated anion channel gene allele in a biological sample of the patient directly, using appropriate probes to a serotonin-gated anion channel, or indirectly, by phenotyping, and;

(b) correlating the genotype or phenotype with appropriated drug and/or dosage.

The presence or absence of a specific serotonin-gated anion channel allele indicates a predisposition, or lack thereof, to respond to serotonin-mediated therapies.

In another aspect, the invention claims a method for identifying a gene that is structurally related to a serotonin-gated anion channel. This method involves identifying a gene by designing probes or primers, including degenerate oligonucleotides, to specific sequences. These primers or probes encode structurally significant amino acid sequence (e.g., the sequence that forms the transmembrane portions of the serotonin-gated anion channel), and are used to screen large genomic or cDNA libraries. If a PCR approach is utilized, the primers are optionally designed to allow cloning of the amplified product into a suitable vector. PCR is particularly useful for screening cDNA libraries from rare tissue types. The method also includes identifying a gene using antibodies, using nucleic acid or amino acid scanning databases and computer programs, and screening for

genes that function in a manner similar to, or different from, a serotonin-gated anion channel.

In a related aspect, the invention features the nucleic acid sequence identified by the method of identifying a gene which is structurally related to a serotonin-gated anion channel. This gene may be isolated from nematodes or mammals, preferably from rodents, and most preferably from human.

In another aspect, the invention features a transgenic, or other mutant animal, that over-expresses or under-expresses a serotonin-gated anion channel, or expresses a dominant-negative serotonin-gated anion channel. The invention includes a nematode or a non-human mammal, for example, a mouse, as the animal. In one embodiment, the animal over-expresses a serotonin-gated anion channel that is constitutively active.

In two additional aspects, the invention features a transgenic animal and methods of using the animal for the detection of therapeutics for conditions associated with serotonin-mediated cellular responses. Preferably the animal over-expresses a serotonin-mediated anion channel polypeptide, either wild-type or mutant, or expresses an antisense RNA to a serotonin-gated anion channel or a serotonin-gated anion channel fragment. In one embodiment, the animal also has a genetic predisposition to conditions associated with serotonin-mediated cellular responses.

In yet another aspect, the invention features a method for identifying a compound that modulates the activity of a serotonin-gated anion channel by exposing a nematode to a test compound, assaying the rate of locomotion, and comparing the locomotion rate to that of a nematode receiving no test compound, serotonin, or a placebo, where a modulation in the rate of locomotion indicates a

compound that modulates the activity of a serotonin-gated anion channel. The test compound may be applied at various concentrations. In addition, the nematodes used in the screen may be bacterial-lawn deprived prior to beginning the screen.

In still another aspect, the invention features a method for identifying a
5 compound that modulates the activity of a serotonin-gated anion channel. The method involves exposing a nematode to a test compound, quantifying the number of nematodes actively swimming after exposure to the compound, and comparing that number to that of a control receiving no test compound, serotonin, or a placebo, where a modulation in the number of actively swimming nematodes
10 indicates a compound that modulates the activity of a serotonin-gated anion channel. The test compound may be applied at various concentrations. In addition, the nematodes used in the screen may be bacterial-lawn deprived prior to beginning the screen.

By “treatment” is meant the submission or subjection of an animal, cell,
15 lysate or extract derived from a cell, or molecule derived from a cell to a test compound or stimulus to a serotonin-mediated response.

By a “test compound” is meant a chemical, be it naturally-occurring or artificially-derived, that is surveyed for its ability to modulate serotonin-mediated cellular responses, by employing one of the assay methods described herein. Test
20 compounds may include, for example, peptides, polypeptides, synthetic organic molecules, naturally occurring organic molecules, nucleic acid molecules, and components thereof.

By “treat” is meant to submit or subject an animal, cell, lysate or extract derived from a cell, or molecule derived from a cell to a test compound or
25 stimulus to a serotonin-mediated response.

By a "substantially pure polypeptide" is meant a polypeptide that has been separated from the components that naturally accompany it. Typically, the polypeptide is substantially pure when it is at least 60%, by weight, free from the proteins and naturally-occurring organic molecules with which it is naturally associated. Preferably the polypeptide is a serotonin-gated anion channel polypeptide that is at least 75%, more preferably at least 90%, and most preferably at least 99%, by weight, pure. A substantially pure serotonin-gated anion channel polypeptide may be obtained, for example, by extraction from a natural source (e.g., a neuronal or smooth muscle cell), by expression of a recombinant nucleic acid encoding a serotonin-gated anion channel polypeptide, or by chemically synthesizing the protein. Purity can be assayed by any appropriate method, e.g., by column chromatography, polyacrylamide gel electrophoresis, agarose gel electrophoresis, optical density, or HPLC analysis.

A protein is substantially free of naturally associated components when it is separated from those contaminants which accompany it in its natural state. Thus, a protein which is chemically synthesized or produced in a cellular system different from the cell from which it naturally originates will be substantially free from its naturally associated components. Accordingly, substantially pure polypeptides include those derived from eukaryotic organisms but synthesized in *E. coli* or other prokaryotes.

By a "purified nucleic acid" is meant a nucleic acid that is free of the genes which, in the naturally-occurring genome of the organism from which the nucleic acid of the invention is derived, flank the gene. The term therefore includes, for example, a recombinant DNA that is incorporated into a vector, into an autonomously replicating plasmid or virus, or into the genomic DNA of a

prokaryote or eukaryote, or which exists as a separate molecule (e.g., a cDNA or a genomic or cDNA fragment produced by PCR or restriction endonuclease digestion) independent of other sequences. It also includes recombinant DNA that is part of a hybrid gene encoding additional polypeptide sequence.

5 By a "serotonin-gated anion channel" is meant a channel whose opening is regulated by serotonin binding to the channel. The opening of the channel selectively permits passage of anions from one side of the channel to the other. In one embodiment, the anion is chloride. Preferably the nucleic acid sequence encoding a serotonin-gated anion channel hybridizes to a *mod-1* nucleic acid
10 sequence.

By a "*mod-1* gene" is meant a gene encoding a polypeptide that is a serotonin-gated anion channel. In one embodiment, the *mod-1* gene is from *C. elegans*.

By a "MOD-1 protein" or "MOD-1 polypeptide" is meant a polypeptide
15 or fragment thereof, encoded by the *mod-1* gene. In one embodiment, the MOD-1 protein or polypeptide is from *C. elegans*.

By "specifically binds" is meant an antibody that recognizes and binds to a serotonin-gated anion channel, but which does not substantially recognize and bind to other molecules in a sample, e.g., a biological sample that naturally
20 includes other proteins.

By "mutant" is meant different from what normally appears, occurs, or functions. As used herein, the term refers to a nucleic acid sequence that is different from the wild-type sequence. This term also describes a protein encoded by the mutant nucleic acid sequence. The term also means an organism that
25 contains a mutant nucleic acid sequence.

By "biological activity" is meant functional events mediated by a protein. In some embodiments, this includes events assayed by measuring the influx of ions into or out of a cell, or assaying the amount of serotonin binding to a channel. It also includes interactions of a polypeptide with another polypeptide. It also includes events that modify behavior or behavioral states. Such behavior includes, but is not limited to, movement, sexual behavior, or hallucinogenic behavior. Such behavioral states include, but are not limited to, migraine headaches, loss of appetite, gain of appetite, insomnia, inability to wake up, memory loss, nausea or vomiting, gastrointestinal cramps, ability or inability to learn, body temperature deregulation, moods, such as depression or mania, abnormal cardiovascular function, abnormal muscle contraction, and abnormal endocrine regulation.

As used herein, by "modulates" is meant increasing or decreasing the biological activity. Preferably the biological activity is increased or decreased 10% relative to a control. More preferably the biological activity is increased or decreased 50% relative to a control. Most preferably the biological activity is increased or decreased 90% relative to a control.

By "assaying" is meant analyzing the effect of a treatment or exposure, be it chemical or physical, administered to a whole animal or cells derived therefrom. The material being analyzed may be an animal, a cell, a lysate or extract derived from a cell, or a molecule derived from a cell. The analysis may be, for example, for the purpose of detecting current flow across a membrane, the rate of locomotion of an animal, altered gene expression, altered nucleic acid stability (e.g., mRNA stability), altered protein stability, altered protein levels, or altered protein biological activity. The means for analyzing may include, for

example, recording current changes under voltage-clamp, voltage changes in current-clamp, or extracellular potentials, counting movements of an animal under a dissecting microscope, nucleic acid amplification techniques, reporter gene assays, antibody labeling, immunoprecipitation and phosphorylation assays, and other techniques known in the art for conducting the analyses of the invention.

By "neuron" is meant a cell of ectodermal embryonic origin derived from any part of the nervous system of an animal. Neurons express well-characterized neuron-specific markers that include neurofilament proteins, MAP2, and class III β -tubulin. Included as neurons are, for example, hippocampal, cortical, midbrain dopaminergic, motor, sensory, sympathetic, septal cholinergic, and cerebellar neurons.

As used herein, by "measuring" is meant assessing an anion channel activity. Measuring can be done by use of standard electrophysiology voltage-clamping or patch-clamping equipment.

By "condition" is meant a state of being or feeling. Conditions include, but are not limited to, migraine headaches, loss of appetite, gain of appetite, insomnia, inability to wake up, memory loss, nausea or vomiting, gastrointestinal cramps, ability or inability to learn, body temperature deregulation, moods, such as depression or mania, abnormal sexual or hallucinogenic behavior, abnormal cardiovascular function, abnormal muscle contraction, and abnormal endocrine regulation.

By "promoter" is meant a minimal sequence sufficient to direct transcription of an operably-linked gene.

By "operably linked" is meant that a gene and one or more regulatory sequences are connected in such a way as to permit gene expression when the

appropriate molecules (e.g., transcriptional activator proteins) are bound to the regulatory sequences.

By "dominant-negative" is meant a nucleic acid sequence encoding a polypeptide which when expressed acts in a way to inhibit another polypeptide.

- 5 This term also refers to the polypeptide itself. In one embodiment, the polypeptide that is inhibited is a wild-type polypeptide, and the dominant negative sequence encodes a mutant polypeptide of the same gene.

- As referred to herein, by "constitutively active" is meant a nucleic acid sequence that encodes a polypeptide, which when expressed is in an active form at
10 least as, or more often as the wild-type polypeptide is, in a cell in which wild-type polypeptide is naturally expressed. The polypeptide may be in an active form by being phosphorylated, or dephosphorylated, or cleaved from a propeptide to a peptide, or being ligand independent, or being mutated.

- By "transgenic" is meant any cell or organism that includes a DNA
15 sequence (transgene) that is inserted by artifice into a cell and becomes part of the genome of the organism that develops from that cell. As used herein, the transgenic organism is generally a transgenic non-human mammal (e.g., rodents such as rats or mice) or invertebrate (e.g., *Caenorhabditis elegans*).

- By "antisense" is meant a nucleic acid sequence, regardless of length,
20 that is complementary to the coding strand gene encoding a serotonin-gated anion channel. Preferably the antisense nucleic acid is capable of decreasing the activity of a serotonin-gated anion channel when present in a cell that normally is modulated by serotonin. Preferably the decrease is at least 10%, relative to a control, more preferably 25%, and most preferably 95%.

By "expose" is meant to allow contact between an animal, cell, lysate or extract derived from a cell, or molecule derived from a cell, and a test compound or activator of a serotonergic response.

By "characteristics" is meant properties or features. Characteristics include, but are not limited to, the nucleic acid sequence of a gene, or various alleles of a gene, the amino acid sequence of a protein, the level of expression of proteins or mRNA, and altered protein levels in tissues.

By "inhibit" is meant to decrease the level of expression of a serotonin-gated anion channel, or to decrease the function or activity of a serotonin-gated anion channel. Preferably the expression, function, or activity of the channel is decreased at least 25%, more preferably at least 50%, 70%, or 80%, and most preferably at least 95%, compared to a control (e.g., one which is not contacted with a test compound or an antisense nucleic acid).

Brief Description of the Drawings

Fig. 1 shows the genomic sequence of *C. elegans mod-1* (SEQ ID NO: 1).

Fig. 2 shows the cDNA sequence encoding the *C. elegans* MOD-1 polypeptide (SEQ ID NO: 2).

Fig. 3 shows the *C. elegans* MOD-1 predicted amino acid sequence (SEQ ID NO: 3).

~~Fig. 4 shows the structure of the *C. elegans mod-1* cDNA.~~

Fig. 5 is a map of the *C. elegans* strain carrying the ok103 mutation at the *mod-1* locus. The ok103 mutation is a 4135 base pair deletion in the *mod-1* genomic locus.

Fig. 6 shows the genomic sequence of the *C. elegans mod-1* gene with the ok103 mutation (SEQ ID NO: 4).

Fig. 7 shows the genomic sequence of the *C. elegans mod-1* gene with the n3034 mutation (SEQ ID NO: 5).

5 Fig. 8 shows the cDNA sequence of the *C. elegans mod-1* gene with the n3034 mutation (SEQ ID NO: 6).

Fig. 9A is a time trace of the MOD-1 channel activated by serotonin.

Fig. 9B is a graph illustrating a dose response curve of MOD-1 channel activity with respect to serotonin concentration.

10 Fig. 9C is a graph illustrating the peak ionic current conducted by the MOD-1 channel in response to a variety of ligands, including acetylcholine, GABA, glycine, Q-107 (quipazine dimaleate, a 5-HT₃ receptor agonist), and serotonin.

Fig. 10 is a graph illustrating the selectivity the MOD-1 channel has for chloride ions. As the concentration of chloride ions outside of the cell increases, the reversal potential becomes more negative.

Fig. 11 is a time trace of a MOD-1-like response from rat brain RNA.

Fig. 12 is a time trace of a MOD-1-like response of an oocyte injected with rat cortex RNA.

20 Detailed Description of the Invention

MOD-1 is associated with locomotion in *C. elegans*

Hermaphrodites respond to the presence of a bacterial lawn (their food source) by slowing their rate of locomotion. Animals deprived of bacteria for 30

minutes exhibit enhanced slowing when they encounter a bacterial lawn. Genetic, pharmacological, and laser ablation studies demonstrate that this modulatory response is mediated, in part, by serotonin.

Nematodes to be tested in the locomotion assay were picked as L4 animals 16-20 hours prior to the assay. Locomotion was assayed by placing the nematode on an assay plate (prepared by spreading a solution of *E. coli* strain HB101 on NGM agar in 5 cm plates, using a ring with an inner diameter of approximately 1 cm and an outer diameter of approximately 3.5 cm, and allowing the bacteria to grow 13-15 hours at 37°C), observing each nematode under a dissecting microscope for 20 seconds, and counting the number of dorsal-ventral bends that occur in the anterior portion of the body during the interval.

For satiated animals, locomotion rate was assayed by removing five animals from plates with ample bacteria, washing them in S-basal buffer, and transferring them to the clear zone of the bacterial lawn of an assay plate using a capillary pipette. Beginning five minutes after transfer, the number of body bends was counted, as described above. This procedure was performed for each of the 5 animals.

To assay locomotion rates in food-deprived animals, 5-15 animals were removed from plates with ample food, washed twice in S-basal buffer, and transferred to 5 cm NGM agar plates without bacteria. Food-deprived animals were incubated on these plates for thirty minutes at room temperature, and then were transferred to assay plates. Locomotion was assayed, as described above for satiated animals.

The *mod-1* mutants, obtained from the screen, as described above, exhibited a dominant phenotype of lack of decreased locomotion after being

deprived of bacteria and then returned to a bacterial lawn.

MOD-1 is associated with locomotion seen in *C. elegans* exposed to serotonin

Animals to be tested for sensitivity or insensitivity to serotonin in this liquid locomotion assay were picked as L4 animals 16-20 hours prior to assay and the plates were coded so that the experimenter was blind to the genotype of the animals to be scored. On the day of the assay, serotonin (as a creatinine sulphate salt) was dissolved in M9 (at the required concentrations) just before use, and 200 μ l were aliquoted to the wells of a flat-bottomed 96-well polystyrene plate.

Twenty nematodes of each genotype to be tested were then transferred from the plate into a well containing liquid, using bacteria as glue. Care was taken not to hurt the animals while dislodging them from the pick, and the animals were observed immediately after transfer to ensure that all of them began to exhibit swimming motions. Then at various time intervals, the number of nematodes in each well that were still actively swimming was quantified.

The *mod-1* mutants, as described in the previous section, were further characterized using this technique. Animals carrying the n3034 mutation exhibited a dominant phenotype of insensitivity to exogenous serotonin in liquid locomotion assays. Animals carrying the ok103 mutation exhibited a recessive phenotype of insensitivity to exogenous serotonin in liquid locomotion assays.

The following examples are provided to illustrate the invention. These examples should not be construed as limiting.

Example 1: Cloning of the *mod-1* gene

mod-1 Both the wild-type, and mutant *mod-1* cDNAs have been obtained. The

dominant serotonin resistance phenotype of animals carrying the *mod-1(n3034)* allele was used to genetically map *mod-1(n3034)* to a 0.7 map-unit interval on chromosome V. Deficiency analysis showed that the dominant serotonin resistance phenotype is not due to a haploinsufficiency of the *mod-1* locus. The recessive nature of the serotonin resistance phenotype at early time points was exploited to perform standard transformation rescue experiments, and subsequently, the gene was cloned.

Example 2: MOD-1 encodes a ligand-gated ion channel

8603> The protein encoded by the *mod-1* open reading frame responsible for the rescue is structurally similar to ligand-gated ion channels that belong to the nicotinic acetylcholine receptor (nAChR) family. The nAChR family members are all pentameric channels with large N-terminal extracellular ligand-binding domains, four highly conserved transmembrane domains (M1-M4), and relatively divergent cytoplasmic domains between M3 and M4. nAChR family members include channels gated by acetylcholine, glycine, GABA, avermectin, and serotonin. Within the members of the nAChR family, structure-function analysis has been performed primarily on the acetylcholine receptor, but many structural and functional parallels have been seen with the other family members as well. In addition, chimeric channel studies show that there is a great deal of conservation at the functional level, even across the different ligand-gated members of the family. The M2 domains of the various subunits are predicted to line the pore of the channels. Site-directed mutagenesis studies of residues within this domain have demonstrated that ion specificity and modulation of the magnitude and frequency of current flux are determined, at least in part, by the residues that line the pore and

those that are immediately adjacent to the pore on both the extracellular and cytoplasmic sides. Based on primary sequence analysis, MOD-1 appears to be equally divergent from all cloned nAChR family members.

Example 3: *mod-1* forms a serotonin-gated anion channel

Stear MOD-1 was heterologously expressed in *Xenopus* oocytes, injected with 50 nl of *C. elegans* RNA, or MOD-1 was expressed in HEK cells transiently transfected by calcium phosphate precipitation. Forty-eight to 72 hours later, the oocytes or cells were screened under a voltage clamp. Application of 100 nM serotonin elicited large inward currents at a holding potential of -70 mV.

10 Uninjected oocytes and nontransfected cells had no response to 10 μ M serotonin. Application of 1 mM of other agonists of ligand-gated ion channels, such as acetylcholine, GABA, or glycine elicited little or no response from the MOD-1 channel.

Pretreatment of wild-type *C. elegans* with mianserin or methiothepin, 15 serotonin receptor antagonists, prevents food-deprived animals from exhibiting the wild-type enhanced slowing response after they encounter bacteria. For this reason, even though both compounds have thus far been considered primarily to be antagonists of metabotropic serotonin receptors, we tested their abilities to affect MOD-1 in oocytes. The MOD-1 channel was inhibited by mianserin and 20 methiothepin, with approximate K_i values of 19 μ M and 32 μ M, respectively. Pretreatment of *mod-1* mutants with mianserin or methiothepin did not further affect the defective enhanced slowing response of these animals. These data indicate that mianserin and methiothepin interfere with the enhanced slowing response of *C. elegans* by antagonizing the MOD-1 serotonin-gated chloride channel.

Example 4: MOD-1 is permeable to chloride ions

Page 5 Ion selectivity was determined by measuring changes in the reversal potential (voltage at which the serotonin response changes from an inward, negative, to an outward, positive, current) in response to varying the ionic composition of the bath solution. The reversal potential was insensitive to changes in cations (Na^+ or K^+), but shifted by approximately 50 mV for each 10-fold change in extracellular chloride concentration.

Example 5: Antibodies to MOD-1

Using MOD-1 polypeptides described herein, anti-MOD-1 antibodies were produced using standard techniques. Peptides to either the putative N-terminal extracellular domain, or to a putative C-terminal intracellular domain, located between transmembrane-spanning regions III and IV, were synthesized, and coupled to GST using standard techniques. The peptides were used to immunize two different rabbits and three different rats. The antibodies were then affinity purified on a HIS-tagged-MOD-1 affinity column using standard techniques, and were shown to specifically identify GST-MOD-1, by Western blot techniques.

Polypeptides for additional antibody production may be produced by recombinant or synthetic peptide techniques (see, e.g., Solid Phase Peptide Synthesis, 2nd ed., 1984 The Pierce Chemical Co., Rockford, IL; Ausubel et al., *supra*).

Alternatively, monoclonal antibodies may be prepared using a serotonin-gated anion channel polypeptide (or immunogenic fragment or analog) and standard hybridoma technology (see, e.g., Kohler et al., Nature 256:495, 1975;

Kohler et al., Eur. J. Immunol. 6:511, 1976; Kohler et al., Eur. J. Immunol. 6:292, 1976; Hammerling et al., In *Monoclonal Antibodies and T Cell Hybridomas*, Elsevier, NY, 1981; Ausubel et al., *supra*).

Once produced, polyclonal or monoclonal antibodies are tested for specific recognition by Western blot or immunoprecipitation analysis (by the methods described in Ausubel et al., *supra*). Antibodies that specifically recognize a serotonin-gated anion channel polypeptide, as described herein, are considered to be useful in the invention. Anti-serotonin-gated anion channel antibodies, as isolated above, may be used, e.g., in an immunoassay to assay or monitor the level of a serotonin-gated anion channel polypeptide produced by *C. elegans* or a mammal, or to screen for compounds that modulate serotonin-gated anion channel polypeptide production. Anti-serotonin-gated anion channel antibodies may also be used to identify cells that express a serotonin-gated anion channel gene.

Example 6: Cloning of mammalian serotonin-gated chloride channels with biophysical properties similar to the *C. elegans* serotonin-gated anion channel

Based on our isolation of a novel nematode *mod-1* cDNA, the isolation of mammalian nucleic acid sequences encoding a serotonin-gated anion channel, including human sequences, is made possible using the strategies described herein and standard techniques.

I. Expression cloning using *Xenopus* oocytes

A. Poly(A)+ RNA isolated from various tissues types is injected into *Xenopus* oocytes. Initial screening is performed on total Poly(A)+ RNA from human brain, human spinal cord, human testes, rat brain, rat testes, mouse brain, and mouse

testes.

B. Functional expression of serotonin-gated ion channels is assayed by measuring ion current in voltage-clamped oocytes elicited by application of serotonin at a concentration of 100 nM or less. Several strategies can be used to identify those serotonin-gated currents that are likely to be conducted by an anion-selective ionotropic channel, comparable to MOD-1.

1) High affinity for serotonin. We have found that MOD-1 channels are activated by lower concentrations of serotonin than 5-HT_{3a} type serotonin receptors. MOD-1 has a half-maximal response with 50 nM serotonin. For 5-HT_{3a} channels, no response is detectable in 1 μM serotonin, but 10 μM serotonin elicits a robust current. The lower affinity of the 5-HT_{3a} receptor for serotonin is also reflected in its faster and more complete "washout" (reduction of current back to baseline when the drug is washed off) compared to MOD-1. Serotonin-gated anion channels that have a lower affinity for serotonin can also be isolated using the methods, as described above.

2) Shifts in the reversal potential caused by changes in [Cl]_o. In standard external saline (140 mM NaCl, 2 mM CaCl₂, 1 mM MgCl₂, 2.5 mM glucose, and 10 mM HEPES) the reversal potential (E_{rev}) for MOD-1 is about -20 mV, whereas the 5-HT_{3a} current reverses at about 0 mV. Decreasing the extracellular Cl⁻ to 50 mM by

substitution with gluconate, while keeping the cation concentration fixed, will cause E_{rev} of the MOD-1 current to shift to $> +15$ mV whereas E_{rev} for the 5-HT_{3a} current will not be changed.

3) Exclusion of metabotropic (second messenger dependent)

serotonin-gated currents. Ligand binding to metabotropic 5-HT receptors, such as the 5-HT_{1C} receptor, expressed in *Xenopus* oocytes elicits a large Cl⁻ current due to IP₃-triggered release of intracellular Ca²⁺ and subsequent activation of endogenous Ca²⁺-activated Cl⁻ channels. This signaling pathway can be suppressed by direct injection of IP₃, which exhausts the stores of releasable Ca²⁺ and thereby causes the oocyte to be refractory to metabotropic 5-HT receptor responses that depend on internal Ca²⁺ release. Serotonin-gated responses acting through second messenger systems also differ from ionotropic responses in that second-messenger based systems often give rise to oscillations in ion current. These oscillations arise from the dynamic aspects of intracellular Ca²⁺ regulation. In contrast, current conducted by ionotropic receptors always have a monophasic time course.

4) 5-HT_{3a} specific toxin. The 41-amino acid snail venom σ -conotoxin GVIIIA is a potent competitive antagonist of the 5-HT_{3a} channel (IC₅₀ on the order of 50 nM). One can test whether MOD-1, like all other known 5-HT class receptors, is insensitive to μ M concentrations of this conotoxin. This strategy may provide a simple

method for eliminating the only other known serotonin-gated
ionotropic receptors (5-HT_{3a} and 5-HT_{3b}).

5) Suppression of all known forms of serotonin channels. Ideally,
expression cloning of mammalian serotonin-gated chloride channels is
achieved under conditions in which all other known serotonin gated
channels and receptors are blocked. The blockage of these serotonin gated
channels and receptors can be accomplished by bathing the oocyte in
compounds that inhibit their function. For example, the oocytes may be
bathed in a solution containing the calcium chelator BAPTA-AM. The
concentration of BAPTA-AM in the bath is approximately 200 μ M. While
BAPTA-AM blocks other known serotonin gated receptors, it does not
affect the function of MOD-1.

Alternatively, the bath may contain a high concentration of calcium, for
example, approximately 10 mM, that is sufficient to block serotonin gated
cation channels, but does not block MOD-1. In another method, serotonin
gated Na⁺/K⁺ channels may be blocked using, for example, choline chloride
or N-methyl glucamine. In other methods, the bath may contain, specific
serotonin antagonists. For example, granisetron or ondansetron (at
approximately 1 μ M concentrations) may be used to inhibit the serotonin-
gated cation channel.

One skilled in the art can appreciate that a combination of these methods
may provide the maximal blockage of all known serotonin gated ion
channels and receptors. For example, one preferred combination of

serotonin gated channel and receptor blockers is BAPTA-AM and/or choline chloride or N-methyl-glucamine.

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A method to identify a mammalian serotonin-gated chloride channel was carried out essentially as described above. Oocytes were injected with rat cortex
5 RNA. Six days later, the oocytes were bathed in BAPTA-AM (200 μ M) for 2 hours at room temperature, to deplete internal Ca^{++} stores, thereby preventing G-protein-coupled serotonin receptors from having an effect through calcium-dependent second messenger pathways. The oocytes were then screened under a voltage clamp, in a buffer containing 96 mM NaCl, 2 mM KCl, 0.3 mM CaCl_2 , 1
10 mM MgCl_2 , and 5 mM HEPES (pH 7.5), and with 100 mM Tris added. Addition of Tris completely blocks the 5-HT₃ cation channel. Application of 1 μ M serotonin for 1 minute elicited inward currents at a holding potential of -70 mV in about 10% of the oocytes (Fig. 11).

These results indicate that rat brain RNA elicits a MOD-1-like serotonin-
15 activated current from oocytes. This current is not a 5-HT_{3a} (and is very unlikely to be another permeant 5-HT ionotropic cation channel receptor) or a G-protein-coupled serotonin receptor-activated current. The isolation of the specific RNA that mediates these results is achieved, as described below.

In additional studies, oocytes were injected with poly(A)⁺ RNA from rat
20 cortex, striatum, or thalamus, as described above. The oocytes were bathed in 200 μ M BAPTA-AM for 2 hours, and were then screened under a voltage clamp, in a bath solution containing 2 mM Co^{2+} to block 5-HT_{3a} responses. Application of 1 μ M serotonin elicited inward currents at a holding potential of -70 mV in approximately 33% of the oocytes. Fig. 12 is a representative time trace of a

MOD-1-like response from an oocytes injected with rat cortex RNA. These MOD-1-like currents were not detected in oocytes injected with rat RNA from spinal cord, heart, lung, or testes.

C. When a response that fits some or all of the criteria outlined above has been identified, one can size fractionate the RNA as the first step toward isolating a specific RNA (and corresponding cDNA). Our preliminary studies of MOD-1 and data from the cloning of the 5-HT_{3a} cation channel demonstrate that functional serotonin-gated channels can be formed by homomultimers of a single gene product. This result tremendously improves the feasibility of the expression-cloning strategy. A single RNA species is capable of coding for a functional ionotropic channel, which implies that RNA size fractionation should not cause a loss of serotonin response, as might occur with a heteromultimeric channel protein. Sucrose gradients are used to size fractionate total RNA and individual fractions are injected into oocytes to test for serotonin-gated responses. Once a small enough pool has been determined by such methods, the RNA from that pool is used to prepare cDNA libraries in appropriate vectors. Resulting clones are end-sequenced, and RNA is synthesized from distinct clones and tested in oocytes for the required activity. Clones that produce the desired response are then sequenced in their entirety.

If the results from these experiments indicate that the mammalian serotonin-gated anion channel consists of a heteromultimer rather than a homomultimer, then various pools of mammalian RNA are injected into the oocyte along with any RNAs encoding putative serotonin-gated anion channels. The functional expression of serotonin-gated anion channels can be assayed, as described above.

When a pool meets the requirements of contributing to the make-up of a serotonin-gated anion channel, as outlined above, the pool can be further fractionated, and the assays, as described above, are repeated. The methods used to identify and clone the heteromultimers of the serotonin-gated anion channel then proceed, as described above.

Alternatively, a cDNA library, for example, a human or rat brain cDNA library can be functionally screened to identify and clone mammalian serotonin-gated chloride channels. To this effect, a rat brain cDNA library, containing 10^9 plaque forming units from greater than 10^7 clones with insert sizes of 1.3 to 2.5 kb that have been directionally cloned into the expression vector cmvSPORT, was purchased (Gibco). The library was divided into 20 plates. Colonies were pooled from within one plate, and DNA plasmids were isolated and linearized using restriction enzymes. RNA was then synthesized, using standard methods.

Oocytes are injected with the synthesized RNA (50 - 100 ng) and responses to serotonin, in the presence of BAPTA-AM and 2 mM Co^{2+} are recorded. As a control for the quality of the library and RNA synthesis, serotonin was applied to oocytes not exposed to the BAPTA-AM. Large oscillatory currents were observed. Such responses are typical of metabotropic serotonin receptors, and indicate that the quality of the library and the RNA synthesis is good.

II. Electrophysiological screening of endogenous serotonin-gated currents

If the above expression-cloning strategy is not successful, or in the alternative, one can identify MOD-1 like serotonin-gated responses in mammalian cells. Both acutely dissociated neurons and brain-derived cell lines may be screened. Once a cell type with a robust serotonin-gated, ionotropic, anion-

selective current is identified, these cells are used as an enriched source from which to isolate mRNA coding for a MOD-1-like receptor. Poly(A)⁺ RNA is then prepared from the positive tissue or cell line, and the same strategy as the one outlined in I is used to identify the clone(s) responsible for the response.

5 III. Other approaches

In addition to the expression cloning strategies outlined above in sections I and II, complementary approaches can be taken to identify mammalian serotonin-gated chloride channels.

10 A. EST databases are be systematically combed for sequences with similarities to the *mod-1* cDNA or protein sequence. This process is greatly enhanced by the identification of regions of the MOD-1 protein that allow it to be gated specifically by serotonin, and the regions of the protein that are predicted to be important for allowing anions to pass freely through the channel pore. Existing search algorithms for transmembrane topology (MEMSAT, TMAP, PHDtopology),
15 protein fold motifs (TOPITS, UCLA-DOE Structure Prediction Server), and three-dimensional structures (SCOP) are used to search for sequences that may be clear candidates for mammalian homologs of MOD-1. Full-length cDNAs for such candidates are obtained and tested in the above-described oocyte expression system for the desired response.

20 B. Hybridization techniques are used to clone additional serotonin-gated anion channels. These techniques are well known to those skilled in the art, and are described, for example, in Ausubel et al., *Current Protocols in Molecular Biology*,

John Wiley & Sons, New York, NY, 1990, and *Guide to Molecular Cloning Techniques*, 1987, S.L. Berger and A.R. Kimmel, eds., Academic Press, New York. If desired, a combination of different oligonucleotide probes may be used for the screening of a recombinant DNA library. The oligonucleotides are, for example, labeled with ^{32}P using methods known in the art, and the detectably-labeled oligonucleotides are used to probe filter replicas from a recombinant DNA library. Recombinant DNA libraries (for example, human cDNA libraries, such as brain or testes-derived cDNA libraries) are prepared according to methods well known in the art, for example, as described in Ausubel et al., *supra*, or are obtained from commercial sources.

For detection or isolation of closely related serotonin-gated anion channel sequences, high stringency hybridization conditions are employed; such conditions include hybridization at about 42°C and about 50% formamide; a first wash at about 65°C, about 2X SSC, and 1% SDS; followed by a second wash at about 65°C and about 0.1% SDS, 1X SSC. Lower stringency conditions for detecting a gene encoding a serotonin-gated anion channel having less sequence identity to the nematode *mod-1* gene described herein include, for example, hybridization at about 42°C in the absence of formamide; a first wash at about 42°C, about 6X SSC, and about 1% SDS; and a second wash at about 50°C, about 6X SSC, and about 1% SDS.

C. Oligonucleotides that partially encode, or are complementary to nucleic acids encoding serotonin-gated anion channel-specific oligonucleotides are used as primers in PCR cloning strategies. Such PCR methods are well known in the art and are described, for example, in *PCR Technology*, H.A. Erlich, ed., Stockton

Press, London, 1989; *PCR Protocols: A Guide to Methods and Applications*, M.A. Innis, D.H. Gelfand, J.J. Sninsky, and T.J. White, eds., Academic Press, Inc., New York, 1990; and Ausubel et al., *supra*. Again, sequences corresponding to sequences thought to encode amino acids important for serotonin-gated anion channel structure or function are preferred for use in isolating other sequences structurally and/or functionally related to a serotonin-gated anion channel. Such sequences are used to screen cDNA, as well as genomic DNA libraries. The sequences also include those that are not known to be important for serotonin-gated anion channel structure or function.

- 10 D. Once full-length clones are isolated from the appropriate cDNA library, they are tested in the oocyte, or other suitable cell, for the desired response. The PCR and hybridization cloning strategies, as described above, are enhanced by knowledge of regions of the MOD-1 protein capable of binding serotonin and/or conducting chloride ions. The strategies, however, can be used even without
- 15 identification of regions of the MOD-1 protein capable of binding serotonin and/or conducting chloride ions.

- E. Receptors for small ligands have been found using assays for ligand-binding. Serotonin is immobilized to a solid-support using a linker, and established mammalian cell lines and cells injected with cDNA pools from various tissue
- 20 sources are assayed for binding to serotonin. Cells that bind are isolated and the cDNA from within the cell is isolated using single-cell PCR. This step can be used as an enrichment step before proceeding with strategies outlined in section I. The cDNA clones are sequenced and those that fit the general protein topology

constraints for ligand-gated ion channels are tested for the serotonin-gated anion channel-like characteristics in the oocyte system, or other suitable systems.

E. An antibody to MOD-1 can also be used to detect cross-reacting mammalian proteins. This can be done by co-immunoprecipitations, using the MOD-1
5 antibody, and standard techniques.

Example 7: Screening systems for identifying therapeutics

Based on our experimental results, we have developed a number of screening procedures for identifying therapeutic compounds (e.g., pharmaceuticals to treat disorders associated with serotonin-mediated cellular responses), or leads
10 for such compounds, that can be used in human patients. In particular examples, compounds that specifically down-regulate or specifically increase serotonin-gated anion channel biological activity or the biological activity of their human homologs are considered useful in the invention. Also useful in the invention, are
15 compounds that specifically affect other serotonin receptors and a serotonin-gated anion channel, or other serotonin receptors, but specifically not a serotonin-gated anion channel. In general, the screening methods of the invention involve screening any number of compounds for therapeutically active agents by employing any number of *in vitro* or *in vivo* experimental systems. Exemplary methods useful for the identification of such compounds are detailed below.

20 The methods of the invention simplify the evaluation, identification, and development of active agents for the treatment of conditions associated with serotonin-mediated cellular responses, such as depression, panic disorders, obsessive compulsive disorder, sleep disorders, eating disorders, nausea and

vomiting, other gastrointestinal disorders, and migraines, and the side-effects associated with these drugs. In general, the screening methods provide a facile means for selecting natural or synthetic product extracts or compounds of interest from a large population. These candidates are further evaluated and condensed to a few active and selective materials. Constituents of this pool are then purified and evaluated using methods described herein, to determine their ability to modulate serotonin-mediated responses and conditions.

Below we describe screening methods for evaluating the efficacy of a compound for use in the treatment of diseases associated with serotonin-mediated neurotransmission.

Test extracts and compounds

In general, novel drugs for the treatment of serotonin-mediated cellular responses and conditions are identified from large libraries of both natural product, or synthetic (or semi-synthetic) extracts or chemical libraries according to methods known in the art. Those skilled in the field of drug discovery and development will understand that the precise source of test extracts or compounds is not critical to the screening procedure(s) of the invention. Accordingly, virtually any number of chemical extracts or compounds can be screened using the exemplary methods described herein. Examples of such extracts or compounds include, but are not limited to, plant-, fungal-, prokaryotic- or animal-based extracts, fermentation broths, and synthetic compounds, as well as modifications of existing compounds. Numerous methods are also available for generating random or directed synthesis (e.g., semi-synthesis or total synthesis) of any number of chemical compounds, including, but not limited to, saccharide-, lipid-, peptide-, and nucleic acid-based

compounds. Synthetic compound libraries are commercially available from
Brandon Associates (Merrimack, NH) and Aldrich Chemical (Milwaukee, WI).
Alternatively, libraries of natural compounds in the form of bacterial, fungal, plant,
and animal extracts are commercially available from a number of sources,
5 including, but not limited to, Biotics (Sussex, UK), Xenova (Slough, UK), Harbor
Branch Oceanographics Institute (Ft. Pierce, FL), and PharmaMar, U.S.A.
(Cambridge, MA). In addition, natural and synthetically produced libraries are
produced, if desired, according to methods known in the art, e.g., by
combinatorial-chemistry methods or standard extraction and fractionation
10 methods. Furthermore, if desired, any library or compound is readily modified
using standard chemical, physical, or biochemical methods.

In addition, those skilled in the art of drug discovery and development
readily understand that methods for dereplication (e.g., taxonomic dereplication,
biological dereplication, and chemical dereplication, or any combination thereof)
15 or the elimination of replicates or repeats of materials already known for their
effects on compounds associated with serotonin-mediated cellular responses
should be employed whenever possible.

When a crude extract is found to affect serotonin-mediated responses or
conditions, further fractionation of the positive lead extract is necessary to isolate
20 chemical constituents responsible for the observed effect. Thus, the goal of the
extraction, fractionation, and purification process is the careful characterization
and identification of a chemical entity within the crude extract having activities
that affect serotonin-mediated cellular responses. The same *in vivo* and *in vitro*
assays described herein for the detection of activities in mixtures of compounds
25 can be used to purify the active component and to test derivatives thereof.

Methods of fractionation and purification of such heterogenous extracts are known in the art. If desired, compounds shown to be useful agents for the treatment of pathogenicity are chemically modified according to methods known in the art. Compounds identified as being of therapeutic value are subsequently analyzed using any standard animal model of serotonin-mediated cellular responses known in the art.

There now follow examples of systems useful for evaluating the efficacy of a molecule or compound in treating (or preventing) a condition associated with serotonin-mediated cellular responses, and the side-effects resulting from the treatment of these conditions.

Assays to be used for identifying compounds that affect serotonin-mediated cellular responses include assaying locomotion rates of nematodes exposed to test compounds. It also includes adding a test compound to a cell and assaying serotonin-gated anion channel expression at the nucleic acid level or at the polypeptide level. The changes in serotonin-gated anion channel RNA levels can be monitored by Northern blot analysis, or by highly sensitive quantitative RT-PCR assays. The changes in the levels of serotonin-gated anion channel polypeptide can be monitored through the use of antibodies, including standard Western blot analysis, and immunohistochemistry.

The invention also includes assays that measure ionic current through a channel as a means of identifying a compound that affects serotonin-mediated cellular responses. In the presence of an agonist, the serotonin-gated anion channel is likely to be activated, and this will lead to an increase in the current carried through the channel. This change in current flow can be measured using standard electrophysiological methods. In the presence of an antagonist, the

serotonin-gated anion channel is likely to be refractory to the application of serotonin, and less, or no current will pass through the channel. Such changes can be measured using standard electrophysiological methods.

The invention also includes assays that measure the concentration of serotonin, or a test compound required to activate a serotonin-gated anion channel, as compared to the 5-HT₃ receptor. In both HEK cell and *Xenopus* oocyte expression systems, serotonin-gated currents are detectable at lower concentration of agonist (10-50 nM) for MOD-1 receptors than for 5-HT₃ receptors(>10 μ M). This observation provides a tool for exploring the basis of dose-dependent clinical responses. Effects produced by low-dose serotonin or test compounds may be mediated by serotonin-gated anion channels, while effects at 100-fold higher serotonin or test compound concentrations are likely to arise from a combination of serotonin-gated anion channels and 5-HT₃ type receptor activation.

Example 8: Diagnostic probes

cDNA fragments can be used as hybridization probes for allelic markers for haplotype analysis of human disorders or conditions linked to the locus of a serotonin-gated anion channel locus. Such analyses can also be performed using other standard techniques, such as PCR.

Example 9: Pharmacogenetics of responses to therapeutics for serotonin-mediated conditions

A serotonin-gated anion channel can serve as a marker for determining how an individual might respond to a given therapeutic for a serotonin-mediated condition. Genetic analysis of an individual's serotonin-gated anion channel locus

can be completed as described above. Once a group of major mutant alleles has been established, PCR based genotyping assays can be developed to make a molecular diagnosis of an abnormal serotonin-gated anion channel. When information regarding how individuals with a specific serotonin-gated anion channel allele respond to particular therapies is combined with molecular diagnosis techniques, it is feasible to select an optimal therapy to treat serotonin-mediated conditions.

Example 10: Therapies that modulate conditions mediated by serotonergic pathways: Effect of serotonin-gated anion channel genotype

Patients experiencing a specific condition, or set of conditions, mediated by serotonin are placed into one of four treatment groups: placebo or 3 increasing doses of a given drug. During and at the end of the treatment period, the patients are evaluated for the effect of the drug on modulation of the condition(s). The patients are also evaluated for side-effects experienced as a result of drug administration. Patients are also characterized for the presence of various alleles of a serotonin-gated anion channel, and optionally, other serotonin-mediated receptor alleles and/or their respective protein levels. Results of these studies can be correlated to design therapies that provide optimal relief from the serotonin-mediated condition(s), with the fewest side-effects, in a patient with a specific serotonin-gated anion channel allele, or particular protein levels. In addition, other known serotonin-mediated receptors may be characterized and included in the development of the therapeutic protocol.

The patients can also be genotyped for polymorphisms in specific enzymes required for the metabolism of a given therapeutic used in the treatment of

serotonin-mediated conditions. Such enzymes to be assessed include thiopurine S-methyltransferase (TPMT), dihydropyrimidine dehydrogenase (DPD), aldehyde dehydrogenase (ALDH), glutathione S-transferase (GST), uridine diphosphate glucuronosyl-transferase (UGTs), and cytochrome P450 enzymes. Once
5 knowledge of an individual's drug metabolism profile is obtained, therapies to treat serotonin-mediated conditions can be more optimally designed to provide maximal efficacy with minimal side-effects.

Antisense RNA

1. Design of antisense systems. One way in which antisense RNA can be
10 synthesized is through a system. One example of a system includes, but is not limited to a complete panel of adenovirus constructs. The panel may consist of approximately four types of recombinant virus: A) A sense orientation virus for each serotonin-gated anion channel open reading frame; these viruses are designed to massively overexpress the recombinant protein in infected cells. B) Antisense
15 orientation viruses in which the viral promoter drives the synthesis of an mRNA of opposite polarity to the serotonin-gated anion channel RNA, thereby shutting off host cell synthesis of the targeted protein coding region. C) Sub-domain expression viruses; these constructs express only a partial serotonin-gated anion channel protein in infected cells. D) Control viruses; functional analysis of serotonin-gated anion
20 channel requires suitable positive and negative controls for comparison.

2. Confirmation of recombinant adenovirus function. Verification of the sense adenovirus function involves infection of tissue culture cells and determination of protein expression levels. This can be done by Western blot analysis. Functional

analysis of the antisense viruses may be done at the RNA level using either Northern blots of total RNA harvested from infected tissue culture cells or ribonuclease protection assays. Western blot analysis of infected cells may be used to determine whether the expressed antisense RNA interferes with serotonin-gated anion channel expression in the host cell.

3. *Documentation that serotonin-gated anion channel over-expression results in increased serotonin-gated anion channel activity.* Determination of whether serotonin-gated anion channel over-expression results in increased serotonin-gated channel activity can be done by measuring the ionic current across a membrane elicited by serotonin using standard voltage-clamping techniques. The surface area of the membrane to be analyzed is pre-determined and remains constant for assaying both over-expressing and control samples.

4. *Documentation that antisense serotonin-gated anion channel over-expression results in decreased serotonin-gated anion channel activity.* Having confirmed that serotonin-gated anion channel over-expression renders cells more likely to exhibit increased serotonin-gated anion channel activity, one may examine whether the antisense adenoviruses render the same cells resistant to the channel activity, using the above-described methods.

5. *Identification of antisense oligonucleotides.* Concomitant to the adenovirus work, a series of antisense oligonucleotides to various regions of a serotonin-gated anion channel can also be designed. A generally-accepted model of how antisense oligonucleotides function proposes that the formation of RNA/DNA duplexes in the

nucleus activates cellular RNase H enzymes which enzymatically degrade the mRNA component of the hybrid. Virtually any region of the mRNA can be targeted, and therefore choosing an appropriate sequence to target is somewhat empirical. One site frequently targeted is the translation initiation site.

5 Alternatively, one can design antisense oligonucleotides that systematically “walk” down a nucleic acid sequence of interest. Many factors, including secondary structure of the target mRNA and the binding affinity of the targeted sequence determine whether a particular oligonucleotide will be effective, necessitating several oligos for a serotonin-gated anion channel. Oligonucleotides to serotonin-
10 gated anion channel mRNA can be made based on the available computer algorithms for predicting binding affinities and mRNA secondary structures. These and other oligonucleotides may be tested for their ability to target their respective mRNAs for degradation using Northern blot analysis.

6. *Optimization of oligonucleotides.* A secondary round of oligonucleotides may be
15 made when effective target regions have been identified. These oligonucleotides target sequences in the immediate vicinity of the most active antisense oligonucleotides identified using methods such as those provided above. A second round of testing by Northern blot analysis may be required.

7. *Testing antisense oligonucleotides in vitro.* Following successful identification
20 and optimization of targeting oligonucleotides, one may test these antisense oligonucleotides in tissue culture cells. Experimental procedures may parallel those used in the recombinant antisense adenovirus work. Negative control oligonucleotides with mismatch sequences are used to establish baseline or non-

specific effects. Assisted transfection of the oligonucleotides using, for example, cation lipid carriers may be compared to unassisted transfection. Confirmation of the effectiveness of specific antisense oligonucleotides prompts synthesis of oligonucleotides with modified phosphodiester linkages, such as phosphorothioate or methylimino substituted oligos. These modified oligonucleotides may also be tested *in vitro*.

Another therapeutic approach within this invention involves administration of recombinant protein fragments or antibodies to a serotonin-gated anion channel, either directly to the site where modulation of serotonin transmission is desirable (for example, by injection) or by systemic administration (for example, by any conventional recombinant protein administration technique).

The dosage of serotonin-gated anion channel, the serotonin-gated anion channel fragment, serotonin-gated anion channel mutant protein, or antibody to a serotonin-gated anion channel depends on a number of factors, including the size and health of the individual patient, but, generally, between 0.1 mg and 100 mg inclusive are administered per day to an adult in any pharmaceutically acceptable formulation.

Administration

A serotonin-gated anion channel mutant protein or protein fragment, gene encoding the same, gene encoding a serotonin-gated anion channel antisense RNA, or modulator of a serotonin-gated anion channel may be administered within a pharmaceutically-acceptable diluent, carrier, or excipient, in unit dosage form. Conventional pharmaceutical practice may be employed to provide suitable formulations or compositions to administer the compounds to patients suffering

from a disease or condition associated with the serotonergic pathway.

Administration may begin before the patient is symptomatic. Any appropriate route of administration may be employed, for example, administration may be parenteral, intravenous, intraarterial, subcutaneous, intramuscular, intracranial, intraorbital, ophthalmic, intraventricular, intracapsular, intraspinal, intracisternal, intraperitoneal, intranasal, aerosol, suppository, or oral administration. For example, therapeutic formulations may be in the form of liquid solutions or suspensions; for oral administration, formulations may be in the form of tablets or capsules; and for intranasal formulations, in the form of powders, nasal drops, or aerosols.

Methods well known in the art for making formulations are found, for example, in "Remington's Pharmaceutical Sciences," (Remington: The Science and Practice of Pharmacy, 19th ed., A.R. Gennaro, ed., Mack Publishing Co., Easton, PA, 1995). Formulations for parenteral administration may, for example, contain excipients, sterile water, or saline, polyalkylene glycols such as polyethylene glycol, oils of vegetable origin, or hydrogenated naphthalenes. Biocompatible, biodegradable lactide polymer, lactide/glycolide copolymer, or polyoxyethylene-polyoxypropylene copolymers may be used to control the release of the compounds. Other potentially useful parenteral delivery systems for serotonin-gated anion channel modulatory compounds include ethylene-vinyl acetate copolymer particles, osmotic pumps, implantable infusion systems, and liposomes. Formulations for inhalation may contain excipients, for example, lactose, or may be aqueous solutions containing, for example, polyoxyethylene-9-lauryl ether, glycocholate and deoxycholate, or may be oily solutions for administration in the form of nasal drops, or as a gel.

If desired, treatment with serotonin-gated anion channel mutant proteins or serotonin-gated anion channel fragments, related genes, or other modulatory compounds may be combined with more traditional therapies for therapies associated with serotonin-mediated cellular responses.

5 Example 11: Transgenic mice

Transgenic mouse expression vectors, including neuronal, testes, and smooth muscle cell-specific promoter constructs can be constructed. Founder mice that are viable for most of these constructs can be identified, and breeding colonies can be developed. These mice will likely be prone to modulation of the serotonin-gated anion channel within tissue types in which the promoter is active. Thus the mice provide an excellent resource for testing the efficacy of antisense oligonucleotides, and for screening for therapeutics associated with serotonin-mediated cellular responses and the side-effects associated with these therapeutics. Standard mouse drug screening models and gene delivery protocols may be employed to utilize the mice for this purpose.

Example 12: Characterization of *mod-1* mutants

A single base transition mutation in the *mod-1* coding sequence in *n3034* mutants was found. This missense mutation is predicted to change alanine 281 (codon GCT) to a valine (codon GTT) within the predicted M2 transmembrane domain of the MOD-1 protein (a domain thought to be critical for channel function). Site-directed mutagenesis was used to introduce this C-to-T (A281V) mutation into a 5.5 kb minimal fragment that rescues the mutant phenotype of serotonin resistance, and transgenic animals carrying extrachromosomal arrays of the fragment,

Ex[MOD-1(A281V)], were generated. These transgenic animals displayed resistance to exogenous serotonin, confirming that the C-to-T (A281V) change in the *mod-1* locus was sufficient to cause serotonin resistance.

The effect on channel function of the MOD-1(A281V) substitution in the *mod-1(n3034)* mutant was also examined. When cRNA encoding MOD-1(A281V) was injected into oocytes, there were no serotonin-gated responses. When the mutant cRNA was co-injected with approximately a four-fold excess of wild-type *mod-1* cRNA, the magnitude of the current through the wild-type channels was dramatically reduced compared to oocytes that had been injected in parallel with the same amount of only the wild-type cRNA. These findings indicate that the MOD-1 channel is multimeric and that mutant MOD-1(A281V) channel subunits interfere in a dominant manner with the function of wild-type MOD-1 channel subunits.

To determine the phenotypic consequence of completely eliminating *mod-1* function the deletion allele of *mod-1*, (*ok103*), was analyzed. This mutant was obtained by screening libraries of mutagenized animals using PCR to identify large deletions in the *mod-1* genomic locus. *mod-1(ok103)* mutants, when food deprived, were defective in the enhanced slowing response, but was not defective in the basal slowing response displayed by well-fed wild-type animals. The deletion mutant was also resistant to exogenous serotonin. The serotonin resistance caused by the deletion allele was completely recessive throughout the 20 minute time course of serotonin exposure, which is consistent with our observation that animals heterozygous for large chromosomal deficiencies that uncover the *mod-1* genomic locus are not serotonin resistant. The molecular nature of the *mod-1(ok103)* mutation suggests that it is a null allele. That null alleles confer the same phenotype as that conferred by the Ex[MOD-1(A281V)] extrachromosomal array suggests that